AD

AD-E402 746

Special Publication ARFSD-SP-96002

COMPOSITE MATERIALS

Max Lee

September 1996

COMMITTED TO EXCELLENCE

US ARMY
TANK AUTOMOTIVE AND
ARMAMENTS COMMAND

ARMAMENT RDE CENTER

U.S. ARMY ARMAMENT RESEARCH, DEVELOPMENT AND ENGINEERING CENTER

Fire Support Armaments Center

Picatinny Arsenal, New Jersey

REPORT DOCUMENT PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
September 1996

3. REPORT TYPE AND DATES COVERED

4. TITLE AND SUBTITLE
COMPOSITE MATERIALS

5. FUNDING NUMBERS

6. AUTHORS
Max Lee

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
ARDEC, FSAC
Precision Munitions, Mines and Demolitions Division (AMSTA-AR-FSP-E)
Picatinny Arsenal, NJ 07806-5000

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
ARDEC, LSED
Information Research Center (AMSTA-AR-LSL)
Picatinny Arsenal, NJ 07806-5000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
Special Publication
ARFSD-SP-96002

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

This report contains general information on composite materials. It describes the classification, fabrication, and mechanics of composite materials. This report also outlines the basic design practice for composite materials.

14. SUBJECT TERMS Parameters Laminar Properties Polymer Composite materials Matrix In-site Resin-based Dielectric Post-curing cycles CAD/CAM/

15. NUMBER OF PAGES 18

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std Z39.18
298-02

CONTENTS

INTRODUCTION

Composite materials were discovered and used by man thousands of years ago. Ancient people realized that composite materials had better strength and performance than single elements. The early swords in ancient society were made by forging different types of steels together in laminated layers. This produced a high strength blade. The famous Samurai sword was produced in this manner. In ancient Egypt, bricks were strengthened by putting in plant fibers. These are good examples of ancient technology using composite materials.

WHAT IS COMPOSITE MATERIAL?

Composite materials can be easily found in everyday environments. Plywood, concrete, metal alloy, construction materials, and ceramics are good examples of composite materials. A composite material is a material composed of two or more distinct substances that retain their individual identities and properties. Composite materials have superior performance over individual components that make up the composite materials.

CLASSIFICATION OF COMPOSITE MATERIALS

There are three major types of composite materials. However, before identifying the composite materials, definition of a matrix is needed. A matrix is the material that holds the component(s) together to form the composite material. The matrix must be able to be forced around the component(s) during some stage in the manufacturing process of the composite material. There are a few common matrix materials. Carbon, ceramic, glass, metal, and polymer are some of the general types of matrices. Polymers are the most widely used matrices in the industry due to their wide range of applications, availability, and properties. Polymers are easily processed and have good mechanical and dielectric properties.

The three major types of composite materials are:

Fibrous Composites - Fibrous composites are composed of fiber materials held together by a matrix. Reinforced plastics and fiber glass are some of the common fibrous component materials.

Laminar Composites - Laminar composites are composed of layers of materials held together by a matrix binder. Plywood, safety glasses, plastics, films, and paper are laminar composite materials.

Particulate Composites - Particulate composites are materials formed by dispersing particles into a matrix which holds them together. These particles can be any shape and size. They can be beads, rods, crystalline, or whiskered. Concrete and wood particle board are two common examples of particulate composite materials.

MECHANICS OF COMPOSITE MATERIALS

A composite material is a mixture of two or more single materials. Its mechanical properties such as density, melting point, yield stress, and elasticity, can be very different from a single material. The mechanical behavior and properties of the composite material can be estimated and predicted by some sophisticated equations and calculations; however, its actual mechanical properties must be determined by research and testing.

Mechanics of composite materials is a very complicated and lengthy subject. Volumes of texts and references are devoted to just this subject. Therefore, a detailed explanation of this subject will not be discussed in this report.

FABRICATION OF COMPOSITE MATERIALS

Composite material products can be produced by many different methods or processes. It depends on the types of composite materials used and the types of products to be produced. In general, there are three types of fabrication methods; polymer matrix composite, metal matrix composite, and ceramic matrix composite fabrications.

Polymer Matrix Composite Fabrication

Polymer matrix composites (PMC) are, by far, the most developed and most used materials in the industry. Polymer composites touch every corner of every industry; auto, aerospace, construction, consumer goods, electrical products, transportation, etc. The explosive development of the polymer composite industry from 1940 to 1970 was referred to as the plastic age. This industry should continue to outpace all other industries. The basic fabrication processes of polymer composites involved the use of polymers and fibers. Heat is applied to the polymer and fiber. It causes the polymer to melt and bond the fibers to form a composite. Polymers come from many different sources. The natural sources are asphalt, amber, resin, shellac, and others. The chemical sources are petroleum, coal, and agriculture. Fibers can be glass, kevlar, boron, carbon, and others.

Metal Matrix Composite Fabrication

Metal matrix composites (MMC) yield higher strength, higher moduli, and higher service temperatures than PMCs. The fabrication of MMC can be classified into three types:

Solid State Fabrication - Alternate layers of metal fibers are stacked to produce the desired volume. A resin-based matrix is placed around the metal stack. A combination of heat and pressure are applied to the stack to cause the matrix to melt and bond all the metal fibers in place. After consolidation is completed, the composite is removed for application.

Liquid State Fabrication - This technique involves the use of liquid metal and a die to form the composite. First, a porous fiber preform is inserted into a die. Second, molten metal is poured into the preheated die. Pressure is then applied to the molten metal which forces the molten metal to penetrate the fiber preform, bonding the fibers. After solidification is completed, the part is ejected from the die for application.

In-Site Fabrication - This technique involves the use of an eutectic alloy. Molten eutectic alloy is poured into a die or mold. By carefully controlling the solidification rate, the alloy can produce a two-phase microstructure alloy composite. One of the phases is in lamellar or fiber form. This type of fabrication method eliminates the process of physically combining and bonding of the fibers and matrix. The main advantages of this type of fabrication are to improve the rupture strength at high temperature and the thermal stability of the material.

Ceramic Matrix Composite Fabrication

Ceramic materials have some excellent property characteristics. They have high stiffness at very high temperatures. They also have low density and are chemically inert. However, they possess a serious flaw, a lack of toughness. This flaw can be reduced by incorporating fibers. Ceramic matrix composites can be produced in many ways. The most common technique is the slurry infiltration process. A fiber is first passed through a slurry tank containing matrix ceramic powder, then through a carrier liquid and an organic binder, and then wound on a drum and dried. This is followed by cutting, stacking, and consolidating by hot pressing to produce the composite materials.

DESIGN PRACTICE

Designing composite products is very complicated. It is beyond the scope of this report to summarize all the design parameters for the composite products. There are many texts and references devoted to this subject. This report can only serve as a fundamental guide and a starting point in understanding the complexity of composite design.

For the past few decades there was remarkable growth in composites; however, many of the developments and accomplishments are related to aerospace and military applications. Civilian applications are limited in this composite area. The major emphasis in composite design was on automation, increasing productivity, lower scrap materials, lowering labor cost, reducing energy consumptions, and improving reliability.

Due to the rapid growth in the computer industry, great improvement in computer design was made with the introduction of computer-aided-design (CAD), computer-aided-manufacturing (CAM), and computer-aided-engineering (CAE) systems. The designer is now able to use computer systems to design and engineer composite products. The entire production cycle can also be studied by using CAD/CAM/CAE systems for modeling and simulation.

CAD is a system that can aid the designer in the creation, modification, and display of a design. It can be used to produce a three dimensional design illustration of a proposed product.

CAM is a system that can generate manufacturing oriented data, production programming, robotic interfacing, quality control, and plant operations.

CAE is a system that can analyze the design and calculate the performance of the parts. It can also be used to verify service life and safety factors of the parts.

The design of composite parts involves three major considerations; material, production, and design.

Material Considerations

In the past, due to the limitation of the material, design was forced to change to meet the design requirements. Today, the right kind of material with the right type of properties must be selected to meet the design, economics, and service conditions.

The three areas that must be considered during the selection of the materials are: functional property factors, processing parameters, and economics.

Functional Property Factors

The first step is to list all the functional property factors that the part is expected to tolerate. Examples of the properties are tensile strength, impact strength, thermal expansion, and permeability.

Processing Parameters

The next phase in the selection of the right type of composite material involves processing parameters. All the processing parameters must be known to determine the right type of material to be used. Some of the processing parameters to be considered are: a) shape of the component, b) rate of production, c) quantity to be produced, d) performance reliability and quality, e) type of reinforcement, and f) the optimum processing technique.

Economics

The final phase in material selection is to consider the cost of the material. A material which meets all the requirements with the lowest possible cost should be chosen.

Production Considerations

To design a part, the means of production should be taken into consideration before the design is started or finalized. Production information such as forming pressure, temperature required, surface quality, post-curing cycles, and production rate can affect the selection of production methods. The part shape, size, material used, matrix formulations, and other factors can often limit methods of production to one or two possibilities. The feasibility of making special production tooling, the capacity of equipment used, and the material of the part employed, exhibit a close relationship in design and production. A good design must be produced by a wide variety of processing methods.

Design Considerations

The final step in designing a composite part involves the actual design itself. However, designing a composite component is not a simple matter. It involves the collecting and reviewing of a large amount of information and data, performing design studies, and a design analysis. Four areas need to be considered during preliminary design considerations are:

1. Overall Design Parameters - the overall design parameters of the component are produced from the design studies and the information and data collected previously.

2. Overall Design Conditions - the overall design must be reviewed for meeting the functional requirements, reliability requirements, environmental requirements, specifications, and other necessary requirements.

3. Tooling Parameters - to develop tooling parameters for the design, component design must not result in tooling too difficult or too expensive to produce. A good design must take tooling into consideration.

4. Design Analysis - the component must go through design analysis to determine if it meets all the requirements and specifications. Design analysis is the most difficult and complicated exercise. There is a large data base needed to be calculated. The amount of calculations are very large and require the aid of a computer. Finite element and stress analysis of the part are usually performed by CAD systems.

APPLICATION TO AVIONICS EQUIPMENT

Avionics equipment requires lightweight materials to reduce their weight. In today's world, more and more on-board computers and avionics equipment are required for aircraft, especially military aircraft. Reducing the weight of the equipment becomes significant since the payload weight for the aircraft is a very important design factor. Composite materials provide a solution to the problem. They provide light weight and strength that the equipment requires. Composite materials are very beneficial and desirable for the design of avionics equipment.

The U.S. Army's M130 dispenser system is a very good example of the use of composite material. The M130 is an aircraft mounted countermeasures dispenser system used against enemy missiles. The metal housings used on the system are all aluminum alloy. These aluminum alloys provide light weight and strength to the system requirements.

SUMMARY

Composite materials have superior properties over single components which make up composite materials. Composite materials is a rapidly growing technology in the aerospace industry, especially in military applications. Stealth type military aircraft are heavy composite material users for various purposes. However, civilian applications are limited and the growth in this area is slow due to the relatively high cost and flat demand for the materials. Composite materials hold a promising future for the metal industry. It may revolutionize the design of many industries.

REFERENCES

1. Richardson, Terry, Composite: A Design Guide, Industrial Press Inc., 200 Madison Avenue, New York, 1987.

2. Davis, LaRoy W. and Bradstreet, Samuel W., Metal and Ceramic Matrix Composites, Cahners Publishing Company, 221 Columbus Avenue, Boston, Massachusetts, 1970

3. Chawla, Krishan K., Composite Materials, Springer-Verlag, New York, 1987.

4. Christensen, R.M., Mechanics of Composite Materials, John Wiley and Sons, 1979.

DISTRIBUTION LIST

Commander
Armament Research, Development and Engineering Center
U.S. Army Tank-automotive and Armaments Command
ATTN: AMSTA-AR-LSL (2)
AMSTA-AR-GCL
AMSTA-AR-FSP-E (3)
Picatinny Arsenal, NJ 07806-5000

Defense Technical Information Center (DTIC)
ATTN: Accessions Division (12)
8725 John J. Kingman Road, Ste 0944
Fort Belvoir, VA 22060-6218

Director
U.S. Army Materiel Systems Analysis Activity
ATTN: AMXSY-MP
Aberdeen Proving Ground, MD 21005-5006

Commander
Chemical/Biological Defense Agency
U.S. Army Armament, Munitions and Chemical Command
ATTN: AMSCB-CII, Library
Aberdeen Proving Ground, MD 21010-5423

Director
U.S. Army Edgewood Research, Development and Engineering Center
ATTN: SCBRD-RTB (Aerodynamics Technology Team)
Aberdeen Proving Ground, MD 21010-5423

Director
U.S. Army Research Laboratory
ATTN: AMSRL-OP-CI-B, Technical Library
Aberdeen Proving Ground, MD 21005-5066

Chief
Benet Weapons Laboratory, CCAC
Armament Research, Development and Engineering Center
U.S. Army Tank-automotive and Armaments Command
ATTN: AMSTA-AR-CCB-TL
Watervliet, NY 12189-5000

Director
U.S. Army TRADOC Analysis Command-WSMR
ATTN: ATRC-WSS-R
White Sands Missile Range, NM 88002

GIDEP
P.O. Box 8000
Corona, CA 91718-8000